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Challenge: Advancing Energy Informatics to enable Assessable Improvements of Energy Performance in Buildings

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ABSTRACT
Within the emerging discipline of *Energy Informatics* people are researching, developing and applying information and communication technologies, energy engineering and computer science to address energy challenges. In this paper we discuss the challenge of advancing energy informatics to enable assessable improvements of energy performance in buildings. This challenge follows a long-standing goal within the built environment to develop processes that enable predictable outcomes. Implementing this goal in the research framework of energy informatics creates a need for establishing a new underlying assumption, which states that *the impact of energy informatics solutions should be assessable.* This assumption applies to particular building contexts and when solutions act simultaneously. Research based on this assumption will enable new sound processes for the built environment facilitating informed decision for adding intelligent solutions to buildings compared to only favoring passive building improvements.

Categories and Subject Descriptors
C.3 [**Computer Systems Organization**]: Special-purpose and application-based systems.

General Terms
Management, Performance, Design, Human Factors.

Keywords
Energy informatics, energy efficiency, buildings, assessable methods

1. INTRODUCTION
Globally [1] and regionally, in Denmark [2], European Union [3], and United States [4], buildings account for approximately 40% of the total energy consumption. To reduce this percentage and thereby the associated greenhouse gas (GHG) emissions, the energy-performance of buildings has to be improved. Energy-performance of buildings is a focus area of the Danish and European building directives, the US better building initiative, and the IEA-EBC (International Energy Agency's Energy in Buildings and Communities) programme [5]. The Danish building directive's building-class 2020, aims at a 75% reduction relative to 2006 levels [6]. Therefore, society is facing an urgent need to find new innovative methodologies and tools to improve the energy-performance of buildings.

The emerging discipline of *Energy Informatics (EI)* covers research, development and application of, information and communication technologies, energy engineering and computer science to address energy challenges [7]. Existing work within EI broadly falls into two categories: solutions for improving energy efficiency and handling of renewable energy sources. EI solutions for buildings generally focus on adding various elements of intelligence to buildings covering diagnostic of building operation, feedback to occupants and control of equipment and building facilities as surveyed by Goebel et al. [7]. Existing research has approached the area with an assumption that each solution will be a silver bullet. However, to reach future energy efficiency goals, buildings will need to implement many EI solutions and, thereby, we need to be able to answer what the cumulative intelligence that several EI solutions add to a building, and be able to assess what the cumulative impact is on the energy performance when solutions act simultaneously. The problem is that the majority of current EI solutions are not assessable. This situation makes it difficult to integrate EI solutions in the workflows of the built environment and to argue for their benefits compared to passive building improvements.

The underlying community assumption that *ad-hoc silver bullet solutions with unpredictable impacts will satisfy future needs* has to be changed to assume *that the impact of solutions should be assessable in a particular building context also when solutions act simultaneously.* To consider the building context an impact assessment has to include relevant properties, such as occupant behavior, weather conditions, construction typologies, thermal properties, building systems and controls. Enabling EI solutions with an assessable impact creates the foundation for new sound building processes that facilitate making informed decisions for using EI solutions in building construction and improvements, compared to only favoring passive building improvements. In particular, we envision processes that can assess the impact of advancing the intelligence of a building using EI solutions or processes that evaluate for a particular building what combination of increased intelligence and passive-building improvements is

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most effective for increasing the energy performance of a building.

The paper is structured as follows. In Section 2 we provide an overview of the challenges for EI to enable assessable improvements of the energy performance in buildings. In Section 3 we discuss the potential implications in the context of the processes of the built environment. Finally, in Section 4, we conclude the paper by summarizing the posed challenges and research directions.

2. ASSESSABLE ENERGY INFORMATICS

In this section we provide an overview of the challenges associated with advancing EI to provide assessable improvements to the energy performance of buildings. An impact assessment of an EI solution is an estimate, including risks, of the change in the energy performance of a building. The estimate includes changes in consumption of resources available in a building (E.g. heating, cooling, electricity and water) and impacts on occupant comfort and other relevant parameters. Therefore, to be assessable an EI solution requires an assessment method provided by a model or the solution itself that can provide accurate estimates for what the impact of using the solution will be in a given building context. Stakeholder tools will then utilize the assessments in building construction, operation processes or building systems to autonomously utilize the assessments and identify and recommend EI solutions to stakeholders that will improve a building's energy performance. EI solutions here span the broad range of individual solutions and combinations including diagnostic methods for building operation, hardware and software-based sensing and control infrastructures, feedback tools for occupants and managers, and software control algorithms for equipment and building facilities. Figure 1 illustrates the challenge for a given building, considering occupant behavior, weather conditions, thermal properties, construction typologies and building systems, to estimate if a given solution (building improvement) would improve or degrade the energy performance, and if they act simultaneously what the cumulative impact would be. In addition to energy performance other relevant goals, such as, cost, comfort and sustainability might also need to be considered.

2.1 Assessing the Building Context

An important aspect is how to enable assessment methods to take the particular building context into account. One could imagine that either models or data sets are provided that for a particular building describes occupant behavior, weather conditions, thermal properties, construction typologies and building systems. Therefore, an important prerequisite for following this research direction is to advance models and data availability by further developing building information models, building modeling methods and sensing infrastructures for collection of physical building data and occupant behavior data [8]. The community in this connection needs to answer at what level of granularity we need to model and monitor the different parameters including occupancy behavior, weather conditions, thermal properties and occupancy comfort to be able to make accurate assessment estimates.

2.2 Assessing an Energy Informatics Solution

When developing assessment methods the community has to address the broad area of EI solutions. As mentioned earlier this spans diagnostic methods for building operation, hardware and software-based sensing and control infrastructures, feedback tools for occupants and managers, and software control algorithms for equipment and building facilities. Therefore, a central question to answer is what assessment methods apply to the different solutions and what are the commonalities and differences across the solutions. A core challenge in this regard is also the impact of building occupants, which if unsatisfied with a control solution might change behavior in response to the solution, or for a diagnostic solutions might not have the resources or time to respond to alarms or recommendations [9]. Therefore, it is important that assessment methods not only focus on the impact estimates, but also on assessing the risks of a given solution in a

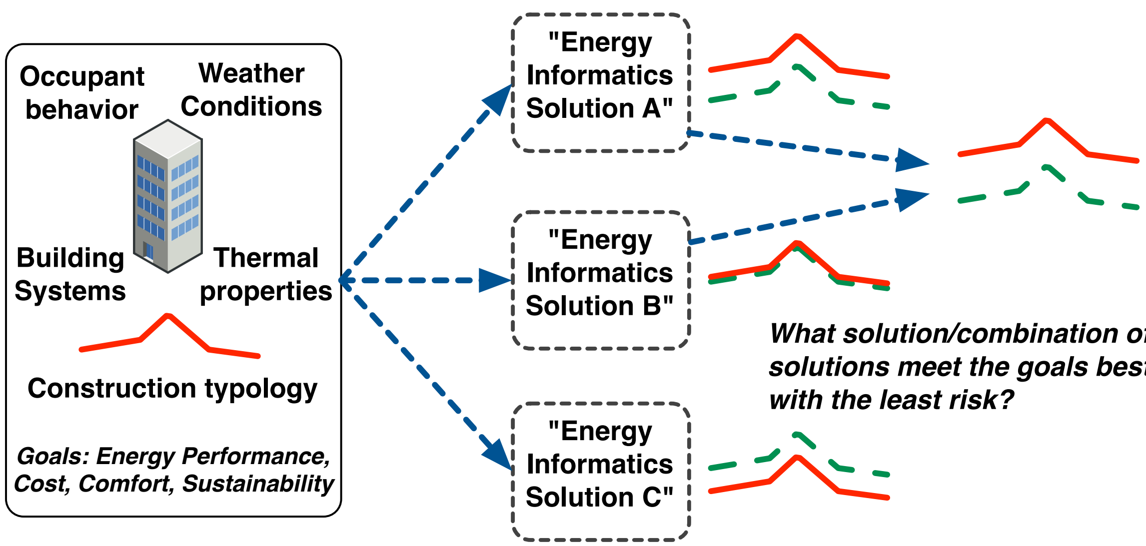

Figure 1. For a particular building we are given a set of goals for improving the energy performance. The performance for the particular building will be impacted by among others the occupant behavior, weather conditions, building systems, thermal properties and construction typology. To improve the energy performance we can consider a number of energy informatics solutions. However, how do we make the improvements of these energy informatics solutions assessable. Furthermore, it is relevant to consider what solution or combination of solutions will meet the goals best and with the least risk.

particular building context. In this regard, all risks might not be quantifiable, but still, even if only provided in a qualitative form, would be relevant to consider for stakeholders of building improvement processes. Another challenge is when solutions require modifications of a building including the placement of sensors or feedback devices. Here, physical properties of the building would be relevant to consider for securing wiring if needed or for esthetic considerations. Again, esthetic considerations are another issue that is impossible to properly quantify which would add to the list of qualitative risks instead.

2.3 Assessing Solutions Acting Simultaneously

As EI solutions cover many different aspects of building operation, a building will have to apply many solutions to improve its energy performance. Therefore, assessment methods have to be able to combine their results to quantify what happens when solutions act simultaneously. One approach would be to develop meta-assessment methods that would be able to combine the individual assessment methods or the models that the individual methods are built upon. However, such a choice would place strict requirements on the individual assessment methods. Therefore, other options should also be considered, including meta-assessment methods that build on knowledge databases, gathering statistics from different buildings for the resulting impacts of different EI solutions acting simultaneously. One might hope that from this data it would be possible to identify trends and quantify the impact given data from a significant amount of buildings and EI solutions. Therefore, a core question for the community is how to enable meta-assessment methods that enable the quantification of the combined impact or increased intelligence of a building when several solutions act simultaneously.

3. CLOSING THE ENERGY GAP: THREE IMPROVEMENT PROCESSES

Outcomes of the anticipated research could deeply affect the way buildings are constructed, operated and renovated and thereby have a large impact on their energy performance. To illustrate the challenge in the context of improvement processes of the built environment, we consider three categories of processes, as presented in the following subsections.

3.1 Closing the energy gap of new buildings by benchmarking and diagnostics

Evidence shows that public and commercial buildings certified according to energy efficiency and sustainability standards like ENERGY Star, LEED and Green Globes often perform worse than predicted and in some cases even worse than non-certified buildings [10]. This gap between actual and predicted energy-performance is typically revealed during building commissioning or as part of building re-commissioning [11, 12]. The main cause is often found to be unforeseen interference between a multitude of implicating factors such as occupant behavior, weather conditions, construction typologies, thermal properties, building systems and controls [12-14]. Hence, benchmarking a building's actual energy-performance with its predicted energy-performance provides an indicator of how well the construction and the specific use of the building matches its original design.

EI benchmarking solutions might be able to identify performance gaps and EI data-driven diagnostics tools might be able to discover their potential causes from model-based simulation of building energy-performance using fine-grained sensing of occupant behavior and building conditions. However, state of the art methods for sensing and modeling occupant behavior, as surveyed in [15], fall short on the types of activities and contexts they cover, and even though numerous building modeling and simulation tools exist [16] they lack support for prediction of building energy consumption based on measured observations of occupant behavior [17, 18]. Inclusion of real occupant behavior is essential as existing studies show that energy unaware behavior can add 33% to a building's predicted energy performance [15].

Therefore, assessable EI solutions are needed for stakeholders to close energy performance gaps of newly constructed buildings. The ability to predict impacts of building improvements allows in this process early identification of EI solutions to apply in commissioning that can help to close the gap for the particular building context. Solutions might also identify flaws in the original predictions for a given building as the use of materials might have changed during the construction phase due to lack of supply or change in stakeholder needs, leading to a change in the interior design of the building. Here, different solutions might be relevant in different building contexts or several solutions acting simultaneously.

3.2 Closing the energy gap by increasing the intelligence

It is commonly recognized by the building industry that increasing the intelligence level of building control has a positive impact on buildings' energy-performance. However, it is equally recognized that intelligent buildings are more difficult to handle correctly in commissioning and operation due to their higher complexity [12]. One way of defining building intelligence is based on the degree that building systems are integrated and coordinated intelligently compared to systems that operate independently without any building-wide coordination [19]. However, the idea of assessment enables another way of describing intelligence by the degree to which EI solutions complement each other when acting simultaneously to improve the energy performance of a building. Furthermore, assessable EI solutions with a predictable impact can enable accurate evaluations of the benefits of increasing the intelligence of buildings versus associated risks including increased complexity as already mentioned. Thereby, one can evaluate which solutions really improve the building intelligence and the energy performance. A promising direction for new EI solutions for control that enable assessable improvements is to work on multi-objective coordination frameworks to optimize building-wide operation of decentralized building systems based on simulation models for building energy performance that include relevant factors such as occupant behavior, weather conditions, construction typologies, thermal properties, and properties of building systems. By integrating simulation as a core component in the tool enables accurate assessment of the impact of such coordination frameworks.

3.3 Closing the energy gap by combining retrofits and intelligence

Leveraging the energy-performance of buildings built during the last decades to present day building standards requires a balanced mix of deep energy-retrofits and intelligent building control. Simply enhancing the building envelope and upgrading technical building equipment is not always the most cost-efficient approach to improve energy-performance of existing buildings. As energy performance of buildings is strongly dependent on occupants' behavior [15, 20, 21], it may be more cost-efficient to find a balanced tradeoff between the depth of energy-retrofits and increasing the building's intelligence. Existing work discusses tradeoffs for different retrofit methods [22, 23] and integration of

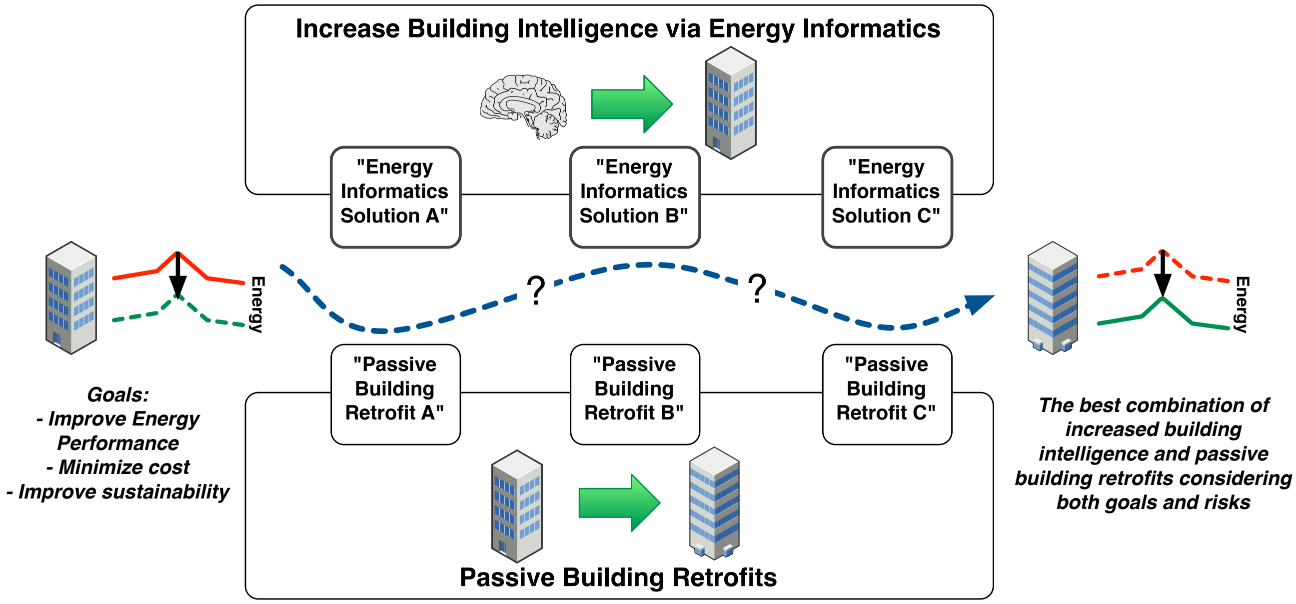

Figure 2. The challenge is to improve the support for walking the path from goals to the best combination of increased building intelligence and passive-building retrofits considering associated risks. Improving the support builds on the ability to assess the energy performance improvements via energy informatics solutions.

occupant behavior models [17], but there is a lack of work discussing tradeoffs between energy-retrofit methods and increasing the level of building intelligence. As stated, there are, typically, two approaches to improving the energy performance of existing buildings: retrofitting or enhancing building intelligence. Retrofitting is the process of upgrading an existing building after it has been built. This implies making changes to the building envelope or even the structure itself at some point after its initial construction and commissioning. The retrofit process is usually executed with the expectation that the availability of new technologies and materials will allow for significant reductions in energy or water consumption. Enhancing building intelligence, on the other hand, implies incorporating new and intelligent technologies that enable buildings to meet various goals, which typically include reduced energy consumption or other relevant goals. The question that further arises is which one of both available methods for improvement of the energy performance of a certain building is the better choice. The answer, however, is not a black-and-white one and it needs a more thorough analysis and introspection, as a more carefully chosen combination of both approaches could yield more favorable results in terms of predefined goals [24]. The challenge that sprouts from this is how to generate that optimal combination of retrofits and building intelligence, and how to assess the impact. Assessable EI solutions would enable the creation of tools for stakeholders to generate customized optimal solutions with predictable impacts to each and every building based on its properties and a set of predefined goals.

To describe what resulting tools might enable for stakeholders we use an illustrative example, presented in Figure 2, where a building in need of energy performance enhancement is presented. Building stakeholders need to define a number of goals to be considered, typically including maximizing energy performance, minimizing cost and maximizing sustainability. Here sustainability covers considerations about the resulting consumption and the resources used in the modification process. Given the availability of methods and tools developed to support the idea of assessable EI solutions, we could then generate an optimal combination of building adjustments to meet the set of predefined goals for a given building. Tools need to provide a careful analysis of all goals, as there are a number of goals that could influence a decision regarding energy performance optimization, typically including cost, time, and occupants' comfort during retrofitting, and sustainability (building materials, resource consumption and environmental effects). Therefore, to support these scenarios future EI tools have to support a holistic analysis of building energy-performance for the different tradeoffs between energy-retrofits and advancing building intelligence. The tools might be developed by combining building modeling, simulation platforms [25], thermal models of the building envelope, assessable EI solutions and concepts for recommendation and decision support systems

4. Conclusions

In this paper we have discussed the challenge of advancing energy informatics to enable assessable improvements of energy performance in buildings. The challenge follows a long-standing goal within the built environment to develop construction and operation processes that enable predictable outcomes. Implementing this goal in the energy informatics research framework creates a need for establishing a new underlying assumption, which states that *the impact of energy informatics solutions should be assessable.* This assumption applies to particular building contexts and when solutions act simultaneously with other solutions for increasing the total intelligence of a building. We have outlined several directions of research that are needed to address the challenge including how to assess different buildings contexts, individual EI solutions and EI solutions acting simultaneously. Research outcomes developed based upon the stated assumption will enable new sound processes for the built environment that facilitate informed decision for adding more intelligent solutions to buildings compared to only favoring passive building improvements. A recently funded US-DK research project named COORDICY managed by the Center for Energy Informatics at the University of Southern Denmark will work on the challenges in the coming years. We hope that the research community will help us address the challenges in future work to advance energy informatics to play an even larger role in improving the energy performance of buildings.

5. Acknowledgment

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